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National Aeronautics and Space Administration
Goddard Space Flight Center
Contract No. NAS-5-3760

9b. ST - RA - LPS - 10384)

ACCOUNTING OF THE AVERAGING EFFECT OF ANTENNA
RADIATION PATTERN DURING MEASUREMENTS
OF MOON'S RADIO EMISSION

by

V. D. Krotikov

[USSR]

N66 86792
(ACCESSION NUMBER)
10
(PAGES)
77810;
(NASA CR OR TMX OR AD NUMBER)

FACILITY FORM 808

(THRU)

None

(CODE)

(CATEGORY)

17 SEPTEMBER 1965

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RADIATION PATTERN DURING MEASUREMENTS
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Transl. into English from

7b. Izv. Vyssh. Ucheb. Zaved.,
~~Radiofizika~~
 7c. Tom 8, No. 3, 453-460
 Izd. Gor'kovskogo Universiteta
 7d. (GOR'KIY), 1965 p 453-460

5.
 by V. D. Krotikov

SUMMARY

The characteristics of Moon's radio emission are considered at accounting of the effect of antenna radiation pattern. It is shown, than when the pattern's width is more than 40° , the received radio emission of the Moon is de facto integral. The results of calculations are utilized for a more precise determination of the parameter δ_1 by the experimental data.

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In order to determine the properties of the upper mantle of of the Moon by the character of its radio emission, received on different antennas, it is necessary to establish the relationship between these properties and the observed characteristics of radio emission. At present the quantitative relationship is established in two extreme cases, corresponding to the width of antenna radiation pattern being much less or much more than the angular dimensions of the Moon [1, 2]. The case is also considered in [1], when the width of antenna radiation pattern equals the angular dimensions of the Moon. However, because of significant mathematical difficulties, the computations of [1] were conducted at simplified assumptions as regards the distribution of surface temperature. On the basis of calculations of the thermal regime of Moon's superficial layer, conducted in [3], the distribution function of surface temperature was established.

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The utilization of that function and of the corresponding theory in the present work (see [1]) provided the possibility of establishing the general theoretical correlations, linking among themselves the radio emission of the center of the disk and that, averaged with the accounting of antenna radiation pattern. This will allow the comparison of experimental data obtained with various radiation patterns.

1. - GENERAL CORRELATIONS

As is well known [1], during measurements of Moon's radio emission one determines only the effective temperature of the Moon averaged by the radiation pattern

$$\bar{T}_{co} = \frac{\int_{-\pi/2}^{+\pi/2} \int_{-\pi/2}^{+\pi/2} T_e(\varphi, \psi, t) F(\varphi, \psi) \cos^2 \psi \cos \varphi d\varphi d\psi}{\int_{-\pi/2}^{+\pi/2} \int_{-\pi/2}^{+\pi/2} F(\varphi, \psi) \cos^2 \psi \cos \varphi d\varphi d\psi}, \quad (1)$$

where $T_e(\varphi, \psi, t)$ is the effective temperature of the portion of the surface with selenographic coordinates φ, ψ ; $F(\varphi, \psi)$ is the radiation pattern of the antenna, expressed in lunar coordinates. We shall assume that the antenna radiation pattern, characterized by the width σ on the half-level of power, constitutes a body of revolution, that the pattern's axis passes through the center of the lunar disk, while the lateral lobes are absent. It is practical to represent a radiation pattern, characterized by a single lobe, by a Gaussian curve. The part of the radiation pattern by power, written in lunar coordinates and bounded by Moon's angular dimensions, has, as is easy to be convinced, the form

$$F(\varphi, \psi) = \exp \left[-\ln 2 (1 - \cos^2 \varphi \cos^2 \psi) \frac{d^2}{\sigma^2} \right], \quad (2)$$

where σ is the width of antenna radiation pattern over half-level of power expressed in radians, d is the mean angular diameter of the Moon.

Inasmuch as the differential characteristics of Moon's radio emission are expressed most simply for the center of the lunar disk, the radio emission of the Moon, averaged with the accounting of antenna radiation pattern is easy to represent through radio emission of the disk's center,

by introducing the appropriate conversion factors. Substituting in (1) the correlation (2) and the expression for $T_e(\varphi, \psi, t)$ in the form of harmonic series (see for example [4]), and effecting the necessary transformations, we shall obtain the expression for \bar{T}_{eo} through the effective temperature of the center of Moon's disk. * :

$$\begin{aligned} \bar{T}_{eo} = & (1-R_{\perp}) \beta_{eo} T_0(0) + (1-R_{\perp}) \sum (-1)^n \times \\ & \times \frac{T_n(0) \beta_{no}}{\sqrt{1+2\delta_n+2\delta_n^2}} \cos [n \Omega t - \varphi_n - \xi(0, 0) - \Delta\xi_n]. \end{aligned} \quad (3)$$

Here $(1-R_{\perp})$ is the emitting capability of the center of the disk,

$$\xi_n(0, 0) = \arctg \frac{\delta_n}{1+\delta_n}$$

is the shift in phase of radio emission of disk's center relative to surface heating. $(1-R_{\perp}) \beta_{eo}$, $T_0(0)$ and $(1-R_{\perp}) \times T_n(0) \beta_{no} / \sqrt{1+2\delta_n+2\delta_n^2}$ are respectively the constant component and the n -th harmonic averaged by coordinates, taking into account of the pattern and the effective temperature. The sign of the n -th harmonic will be determined by the exponents

$$\alpha_n = \frac{(n-1)(n-2)}{2} \quad (n = 1, 2, 3, 4).$$

The coefficient β_{eo} is given by the correlation

$$\beta_{eo} = \frac{1}{1-R_{\perp}} \frac{\int_{-\pi/2}^{+\pi/2} [1-R(\varphi, \psi)] F(\varphi, \psi) \eta_{eo}(\psi) \cos^2 \psi \cos \varphi d\varphi d\psi}{\int_{-\pi/2}^{+\pi/2} F(\varphi, \psi) \cos^2 \psi \cos \varphi d\varphi d\psi}, \quad (4)$$

the coefficient β_{no} by

$$\beta_{no} = \frac{\sqrt{1+2\delta_n+2\delta_n^2} \sqrt{A_n^2+B_n^2}}{1-R_{\perp}}, \quad (5)$$

and the complementary shift in phase is $\Delta\xi_n = \arctg(B_n/A_n)$. The values of A_n and B_n are expressed as follows :

$$A_n = \frac{\int_{-\pi/2}^{+\pi/2} [1-R(\varphi, \psi)] F(\varphi, \psi) \cos [n\varphi + \xi(\varphi, \psi) - \xi(0, 0)] \frac{\eta_n(\psi) \cos^2 \psi \cos \varphi d\varphi d\psi}{\sqrt{1+2\delta_n \cos r' + 2\delta_n^2 \cos^2 r'}}}{\int_{-\pi/2}^{+\pi/2} F(\varphi, \psi) \cos^2 \psi \cos \varphi d\varphi d\psi}; \quad (6)$$

.../...

* In the case under consideration, and contrary to [2], the averaging factors depend on the width of the antenna radiation pattern.

$$B_n = \frac{\int_{-\pi/2}^{+\pi/2} \int_{-\pi/2}^{+\pi/2} [1 - R(\varphi, \psi)] F(\varphi, \psi) \sin[n\varphi + \xi(\varphi, \psi) - \xi(0, 0)] \frac{\gamma_n(\psi) \cos^2 2\psi \cos \varphi d\varphi d\psi}{\sqrt{1 + 2\gamma_n \cos r' + 2\gamma_n^2 \cos^2 r'}}}{\int_{-\pi/2}^{+\pi/2} \int_{-\pi/2}^{+\pi/2} F(\varphi, \psi) \cos^2 \psi \cos \varphi d\varphi d\psi} \quad (7)$$

In the correlations (6) and (7) the normalized dependences of harmonic amplitudes on latitude (see for example [2]) are $\gamma_n(\psi)$, and

$$\cos r' = \frac{1}{\sqrt{\epsilon}} \sqrt{\epsilon - 1 + \cos^2 \varphi \cos^2 \psi}.$$

The expression (3) allows to make use for the interpretation of experimental data, obtained with arbitrary radiation patterns, of correlations, well known for the center of the disk, in connection with which it is necessary to know the factors $\beta_{0\sigma}$ and $\beta_{n\sigma}$ and the additional shift in phase Δt_n . The computation of these factors does not appear to be analytically possible and that is why it was completed with the aid of a computer for various values of ϵ, λ and for a broad interval of the quantity σ variation.

2.- RESULTS OF CALCULATIONS

The dependences of the coefficients $\beta_{0\sigma}$, $\beta_{1\sigma}$, $\beta_{2\sigma}$, $\beta_{3\sigma}$ and $\beta_{4\sigma}$ on width of the pattern over half-level by power are plotted in Fig. 1 - 4. As may be seen from these figures, when the radiation pattern width is $>40'$, the averaging factors $\beta_{n\sigma}$ do not practically vary at further increase of σ and correspond to the values of the coefficients β_n , obtained in [2] for the integral radio emission. This means that for $\sigma \geq 40'$ the width of the pattern does not have to be taken into account during the calculations of the effective temperature of the Moon (that is postulate $F(\varphi, \psi) = 1$ in the correlations (1), (4), (6) and (7)), which corresponds to the case of integral radio emission of the Moon, considered by us earlier [2]. If the width of the pattern is $< 5'$, the coefficients $\beta_{n\sigma}$ are near the unity, and, consequently, the effective temperature corresponds in this case to the brightness temperature at the center of the lunar disk.

As may be seen from Fig. 1, the constant component of the effective temperature depends on the value of the dielectric constant of the Moon's

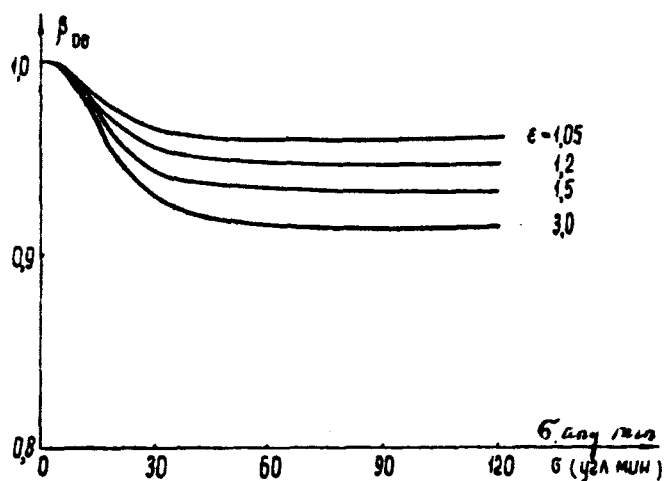


Fig. 1. - Dependence of the factor $\beta_{0\sigma}$ on σ for various values of ϵ .

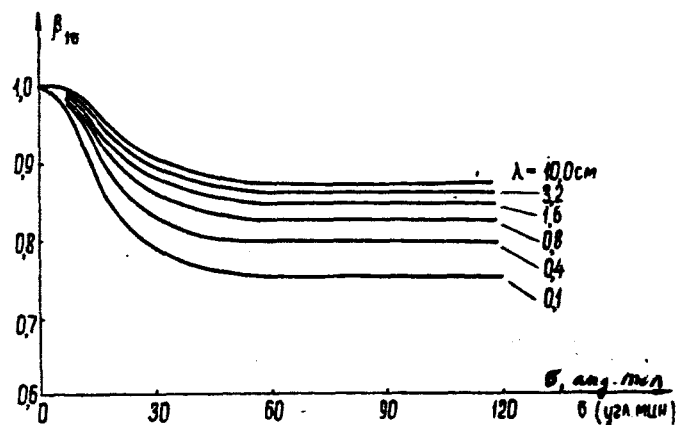


Fig. 2. - Dependence of $\beta_{1\sigma}$ on σ for various wavelengths λ and $\epsilon = 1.5$.

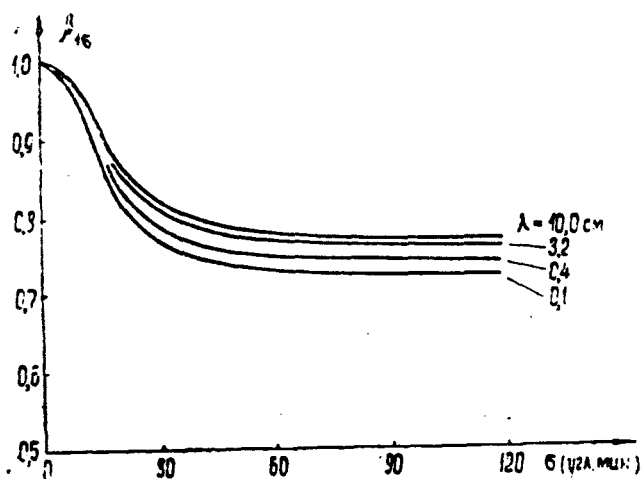


Fig. 3. - Dependence of $\beta_{1\sigma}$ on σ for various wavelengths and $\epsilon = 3$.

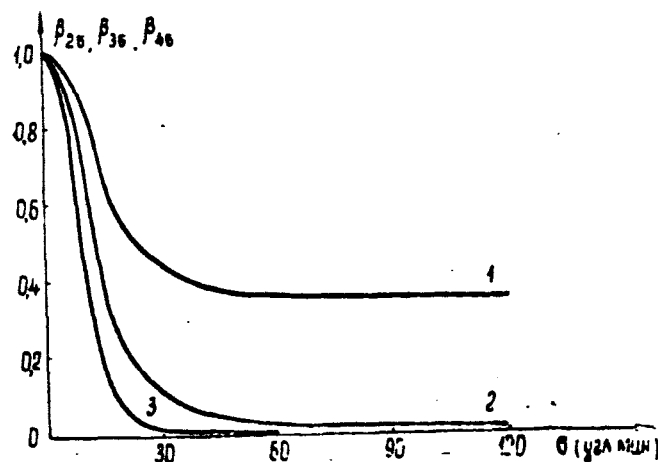


Fig. 4. - Dependence of the factors $\beta_{2\sigma}$ (curve 1), $\beta_{3\sigma}$ (curve 2), $\beta_{4\sigma}$ (curve 3) on σ . The factors $\beta_{2\sigma}$, $\beta_{3\sigma}$ and $\beta_{4\sigma}$ do not practically depend on λ and ϵ .

upper mantle and decreases by about 5 percent when ϵ varies from 1 to 3. The first harmonic of radio emission depends on the dielectric constant as well as on wavelength λ (Figs. 2 and 3).

As was shown by the conducted computations, the higher harmonics of the effective temperature are quite weakly dependent on ϵ and λ . When the dielectric constant and the wavelength vary within the limits $1,2 \leq \epsilon \leq 3$ and $0,1 \leq \lambda \leq 10$ cm the corresponding factors β_n ($n = 2, 3, 4$) vary by no more than 1 percent. In practical calculations of Moon's radio emission this variation may be neglected and we may estimate β_2 , β_3 and β_4 as independent from λ and ϵ . The third and the fourth harmonic of the effective temperature decrease rapidly as the width of the pattern increases to a neglectingly small value (Fig. 4). For $\sigma \geq 40'$ only two harmonics are practically present in the received radio emission. As follows from the computations conducted, the factors β_{A5} (case of arbitrary width of radiation pattern) can be represented with a sufficient precision by the factors β_n for the integral radio emission of the Moon in the form of the simple analytical correlation

$$\beta_{n\sigma} = (1 - \beta_n) \exp \left[-\ln 2 \frac{\sigma^2}{\sigma_{0n}^2} \right] + \beta_n.$$

The values of the coefficients β_n for various ϵ and λ are determined from Figs. 1 — 4 (by the limit value of β_n for $\sigma > 40'$ and the values of σ_{0n} are not dependent on λ and assume the values compiled in Table 1.

TABLE 1

ϵ	σ_{01} (угл. мин.)	σ_{02} (угл. мин.)	σ_{03} (угл. мин.)	σ_{04} (угл. мин.)	σ_{05} (угл. мин.)
1,05	16,5	—	—	—	—
1,2	17,0	—	—	—	—
1,5	17,5	17,5	14,5	13,0	10,0
3,0	18,0	16,5	14,5	13,0	10,0

The averaged effective temperature, taking into account the radiation pattern, lags relative to the variation of the brightness temperature of the center of the lunar disk.

The additional shift in phase occurring at averaging, does not exceed 3° , provided $\sigma \geq 40'$ (case of integral radio emission of the Moon), and is apparently caused by the irregularity of lunar surface's heating. As the radiation pattern width decreases the quantity $\Delta\epsilon$ decreases and may be neglected.

We brought out in Fig. 5, as an example, the phase dependences of Moon's effective temperature, computed for various σ and numerical values of $T_n(0)$ and φ_n , corresponding to $\gamma = (K \rho e)^{-1/2} = 400$ [6], clearly demonstrating the effect of the averaging action of antenna radiation pattern.

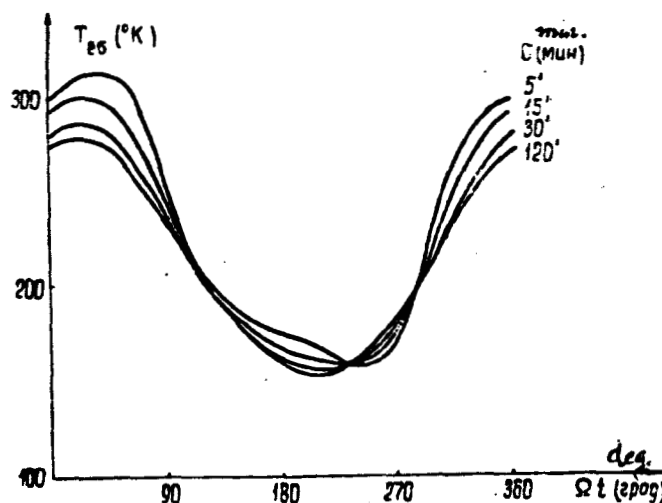


Fig. 5. - Phase dependence of Moon's radio emission in 0.4 cm wavelength for various values of the width σ of radiation pattern.

3. - SOME CONCLUSIONS

The results obtained allow a more precise calculation of the characteristic parameter δ_1 by experimental data obtained with any radiation pattern. As is well known, when investigating experimentally the Moon's radio emission in wavelengths < 10 cm, the ratio of the constant component of the effective temperature to the amplitude of the first harmonic is determined:

$$M_{\text{gkch}} = T_{e0} / \bar{T}_{e1}. \quad (8)$$

The very same ratio, obtained during our calculations, is

$$M_{\text{reop}} = \frac{T_0(0)}{T_1(0)} \frac{\beta_{0\sigma}}{\beta_{1\sigma}} \sqrt{1 + 2\delta_1 + 2\delta_1^2}. \quad (9)$$

Equating (8) and (9) and taking into account, according to [5], that $T_0(0)/T_1(0) = 1.5$, we shall obtain a correlation for the determination

of the parameter δ_1 from the observation data:

$$\sqrt{1 + 2\delta_1 + 2\delta_1^2} = \frac{M_{\text{эксн}} \beta_{0\sigma}}{1,5 \beta_{1\sigma}}$$

For $\epsilon = 1.5$ (see for example [4]), the calculation of the parameter δ_1 was made according to the available experimental data. The results of that calculation are compiled in the Table 2 hereafter.

TABLE 2

λ (cm)	σ (cm ⁻¹) (V.L. MUR.) cm ⁻¹ m ⁻¹	$T_{0\sigma}$ (°K)	$T_{1\sigma}$ (°K)	$M_{\text{эксн}}$	$\beta_{0\sigma}$	$\beta_{1\sigma}$	δ_1	δ_1/λ	$\bar{\delta}_1/\lambda$	Ref.
0.12	10	216	120	1.8	0.99	0.96	0.2	1.4	1.1	[8]
0.18	6	240	115	2.08	0.995	0.99	0.35	1.95	1.95	[7]
0.1	25	230	73	3.15	0.95	0.85	0.73	1.80	—	[8]
0.1	1.6	228	85	2.7	1	1	0.67	1.7	1.97	[9]
0.1	38	201	54	3.8	0.035	0.81	0.97	2.40	—	[10]
0.8	18	197	32	6.16	0.96	0.91	2.20	2.7	—	[11]
0.8	2	211	40	5.28	1	1	1.95	2.4	2.4	[12]
0.86	12	180	35	5.14	0.985	0.97	1.8	2.1	—	[13]
1.25	45	215	36	6.0	0.935	0.85	2.0	1.6	1.6	[14]
1.63	26	224	36	6.22	0.95	0.89	2.2	1.35	—	[15]
1.6	44	208	37	5.63	0.935	0.86	1.9	1.2	1.35	[16]
1.6	44	207	32	6.47	0.935	0.86	2.3	1.45	—	[17]
2.0	4	190	20	9.5	1	0.99	3.9	1.95	1.95	[18]
3.15	9	195	12	16.2	0.99	0.985	7.1	2.25	—	[19]
3.2	6	223	17	13.1	0.995	0.995	5.6	1.75	—	[20]
3.7	40	245	15.5	16.1	0.94	0.88	6.6	2.05	2.0	[21]
3.2	72	210	13.5	15.5	0.93	0.85	6.3	1.97	—	[22]
3.2	87	213	14	15.2	0.93	0.86	6.1	1.9	—	[23]
9.6	100	218	7	31	0.91	0.87	13.2	1.4	1.4	[24]

It may be seen from the Table 2 that the mean value of the ratio δ_1 is near 2. A certain decrease is observed in wavelengths 0.13 and 1.6 cm, which is apparently caused by the increase in the absorption coefficient of these radiowaves in the lunar matter. In order to clarify the nature of this effect, the carrying out of additional measurements in close wavelengths is desirable. In the 9.6 cm wavelength the variable component of radio emission is quite small and the parameter δ_1 is measured with a greater error than in other wavelengths.

The author is grateful to V. G. Ryabikova for programming the problem.

*** THE END ***

8. (Contract No. NAS 5-3760)
1. Consultants & Designers, Inc.,
Arlington, Virginia

Translated by ANDRE L. BRICHANT

on 16 September 1965 10 p. refs

C2553091

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